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APPENDIX 5

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MASS RESOLUTION OF A PARTICLE IDENTIFIER TO BE FLOWN ON ISEE-C

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An instrument designed to identify particle masses (1-56) will be calibrated at the Bevatron during March-June 1977. This instrument consists of ten 5 mm thick Si(Li) detecters preceded by a drift chamber array for trajectory determination. The instrument will be flown on the NASA-ESA ISEE-C satellite scheduled to be launched in July 1978. Instrument operation and calibration results will be discussed.

1. Introduction

Measurements of the masses of the cosmic ray particles (when performed without use of a magnetic field) generally involve observations of small effects. When measuring a small effect we must either have high accuracy instruments or many observations with a less ingenious instrument. Many times a compromise is made and we settle for a few observations from a semi-high accuracy instrument. Then the identification depends on making the best use of the several parameters measured. Mathematically this is achieved by the formulations of a likelihood function which allows assignment of probabilities to each possible particle mass for a given set of observed parameters. But likelihood functions are difficult to formulate and more tractable χ^2 functions provide the same information content, provided the errors in the problem have gaussian distributions.

Using this multi-parameter approach we have predicted instrument resolutions.[1] Application to a solid state detector telescope consisting of ten 5 mm thick Si(Li) detectors predicts mass resolutions better than .2 amu through mass 56 if the following requirements can be met:

1. Detectors flat ($\sigma_t \leq 12\mu$)
2. Pulse resolution = .1% of the maximum pulse expected for a given particle
3. Particle direction relative to the Silicon is measured to an average

accuracy of .3°

Let us now look at the sensors we have developed to achieve this resolution.

2. Method

The Si(Li) detectors were made of Topsil silicon at the Lawrence Berkeley Laboratory. Some average characteristics are:

Active diameter	44 mm
Thickness	4700μ
Noise	140 kev (RMS @ 700 volts)
Leakage	6μA (@ 25° C)

The lithium "dead layer" side of each detector was lapped completely off and a 10μ layer of lithium was re-deposited creating a very thin window. Generally, ^{241}Am in this side of a detector gives a pulse height of 4.525 MeV. A special planer etch process was used when preparing the surfaces in order to reduce mechanical nonuniformity. All detectors were subjected to a two week thermal vacuum test where their noise and leakage were monitored while in vacuum at 25°C for 4 days and 35°C for 10 days. The failure rate in this test was less than 10%.

The thickness variations of the detectors were measured optically and also by passing a beam of heavy ions through the detector. The optical measurements were done using a 3 axis digitized microscope which was calibrated using gage blocks close to the thickness to be measured. The thickness of the detectors was measured on a 3 mm grid over the entire surface. Each individual measurement had an accuracy of 5μ. The detectors selected for further testing had maximum variations less than 20μ from the average and a standard deviation of less than 10μ.

The uniformity of signal when particles are passed through at normal incidence was our most important criterion for detector selection. A total of 22 detectors which had passed all the previous tests were exposed to a 400 MeV/n ^{40}Ar beam at the Bevalac.[2] Enough particles were observed to allow at least .1% accuracy in the pulse height average over each of 80 annular segments of a detector. The results of the particle mapping were in agreement with the optical measurements, indicating the detectors' electronic properties are also quite uniform. Final detector selection was somewhat subjective with emphasis put on the uniformity and the history of noise and leakage. Fortunately, there was an abundance of good detectors.

The size of the silicon detectors and the desire to have a large solid angle lead us to consider either multiwire proportional chambers or drift chambers as the trajectory measuring device. There were several points in favor of drift chambers:

1. Fewer wires, i.e., less to break
2. One amplifier vs. either a delay line or many amplifiers
3. Sufficient gain without exotic gas mixtures

For these reasons we chose to precede the silicon stack with 6 drift chambers.

Monte Carlo calculations of the 6 drift chamber array response to heavy ions and the associated δ rays allowed design of a discrimination scheme which reduced the effect of the δ rays to an acceptable level. The chambers and their associated electronics are described in more detail by Fred Bieser at this conference.

The ISEE-C instrument consists then of 6 drift chambers followed by 10 Si(Li) detectors with the detectors surrounded by a scintillator shield. In order to limit telemetry requirements and to be sure of getting important events (i.e., stopping in the silicon), the following five event types were defined:

1. Stopping, $z \geq 3$, no shield
2. Stopping, $z \leq 2$, no shield
3. Through, $z \geq 3$, no shield
4. Through, $z \leq 2$, no shield
5. Through, $z > 2$, shield

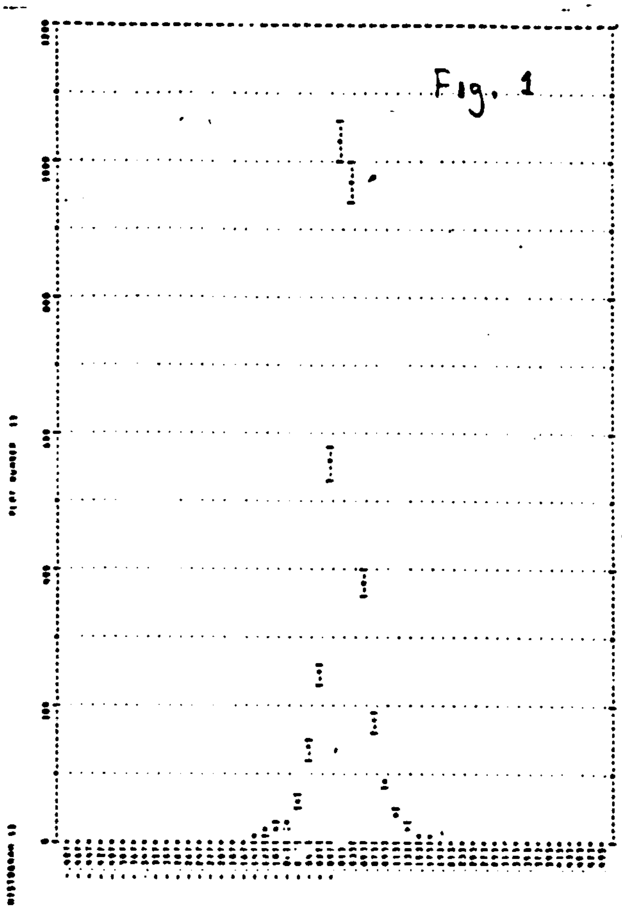
The priority scheme requires that type one events always be telemetered, while a subset of types 2-5 is sent. The thresholds which are used to determine the event type are set by ground command to allow for precise selection and long term drifts. It is also possible to reconfigure the instrument trigger to require any combination of wire chambers and any two silicon detectors. The detector which determines the stopping and through conditions may also be changed. Lastly it is possible to command the instrument to not send any of the event types. The completed instrument weighs 8.5 kg, uses 6.2 watts and transmits 32 bits/sec.

3. Results

A carbon beam at 250 MeV/n was used to begin calibration of the instrument in late March 1977. Three types of data were taken:

1. Drift chamber calibration data which consisted of exposing the instrument to the unfragmented beam at 49 different orientations covering the entire acceptance solid angle.
2. Silicon detector beam calibration data which consisted of varying the beam energy with absorbers so that the particles stop in several positions of each detector of the telescope.
3. Mass and charge calibration data where the beam is fragmented and all isotopes below the beam mass are stopping throughout the telescope.

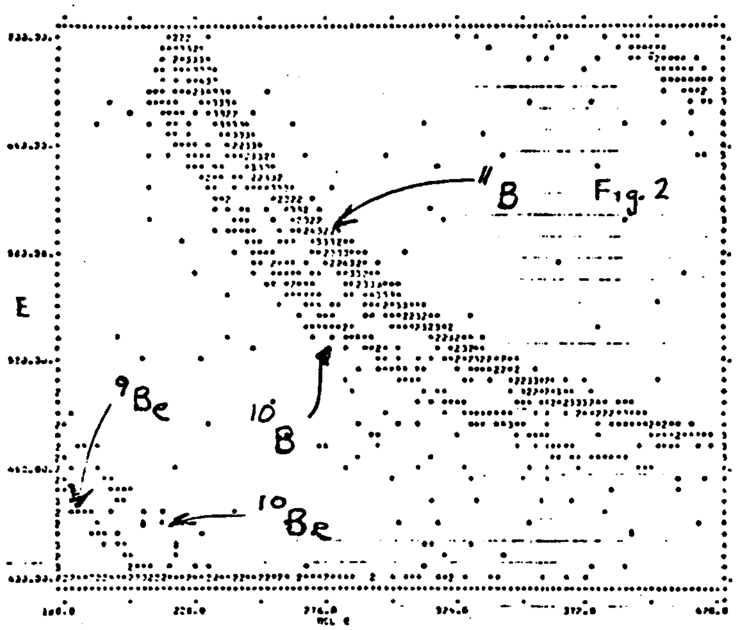
Essentially the same data set was taken using a ^{40}Ar beam two weeks later. We have available at the time of this writing the diagnostic checks of the ^{12}C data made between the two runs.



The drift chamber resolution was the first quantity checked. Fig. 1 shows the tangent of the angle of incidence of the beam as determined by two of the six drift chambers. The standard deviation is ∿.026. This predicts a path length uncertainty of 50μ in each silicon detector. Monte Carlo calculations for ^{12}C predict a 30μ uncertainty in path length assuming chamber resolution is 300μ and all six chambers are used to determine the slope. Thus we feel that when we make use of the information from the other chambers we will achieve the predicted resolution.

The diagnostic tests of the isotopic resolution for fragments of the ^{12}C beam consisted of ΔE vs. E plots for all choices of stopping detector. A representative sample is shown in Fig. 2 for particles stopping in the third detector. Even without using the greater resolution of the multiparameter fit we see quite clear separation of isotopes through ^{11}B. Comparison of these results to the predicted resolution indicates we have achieved our design goals.

We eagerly await the calibration with ^{56}Fe which will begin July 6, 1977.



References:

1. Nuc. Inst. and Meth., 103 (1972), 291.

2. Nuc. Inst. and Meth., 116 (1974), 21.